Phytoplankton regulation in a eutrophic tidal river

Alan Jassby

Department of Environmental Science & Policy, University of California at Davis

The problem. Phytoplankton in the tidal San Joaquin River (Figure 1) is currently of interest because it exerts a net oxygen demand in the Stockton Ship Channel—a section of the lower San Joaquin River—contributing to low dissolved oxygen conditions and thereby interfering with fish habitat, spawning, and migration. It is also a major source of energy and materials for an estuarine food web, at least part of which is food-limited in the Delta. What controls phytoplankton concentration in the river, and how can it be managed? Here, we highlight some relevant results from an analysis of the Interagency Ecological Program's long-term water-quality data.

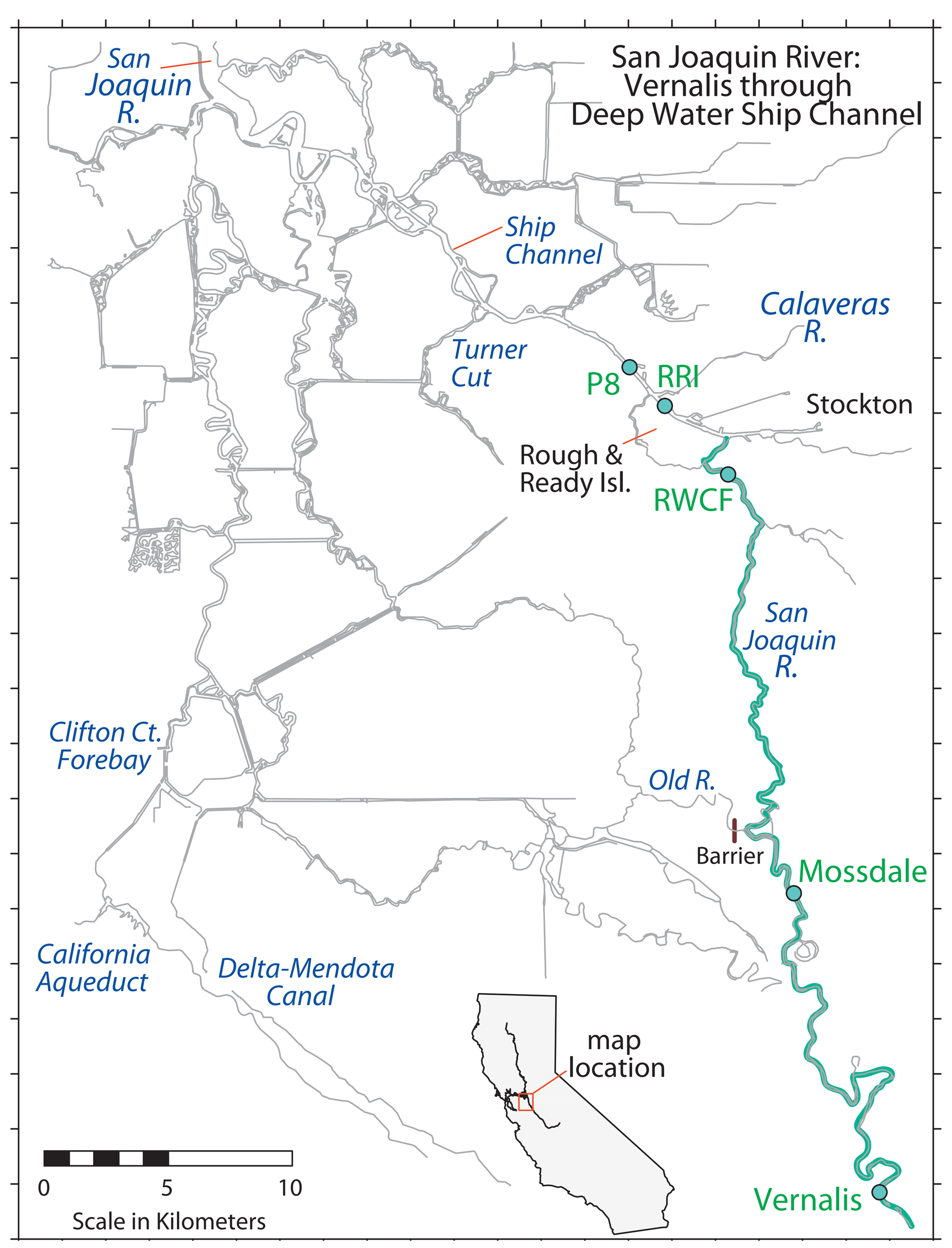

Figure 1. Tidal San Joaquin River from Vernalis through Stockton Deep Water Ship Channel. Green shading denotes the stretch upstream of the Ship Channel.

Control of bloom size. Phytoplankton biomass at Vernalis varies strongly in the historical record, sometimes reaching values in dry years among the highest normally observed in rivers (Figure 2). It is puzzling, though, that the frequency of large blooms seems to have declined since the late 1970s. Has the system changed somehow?

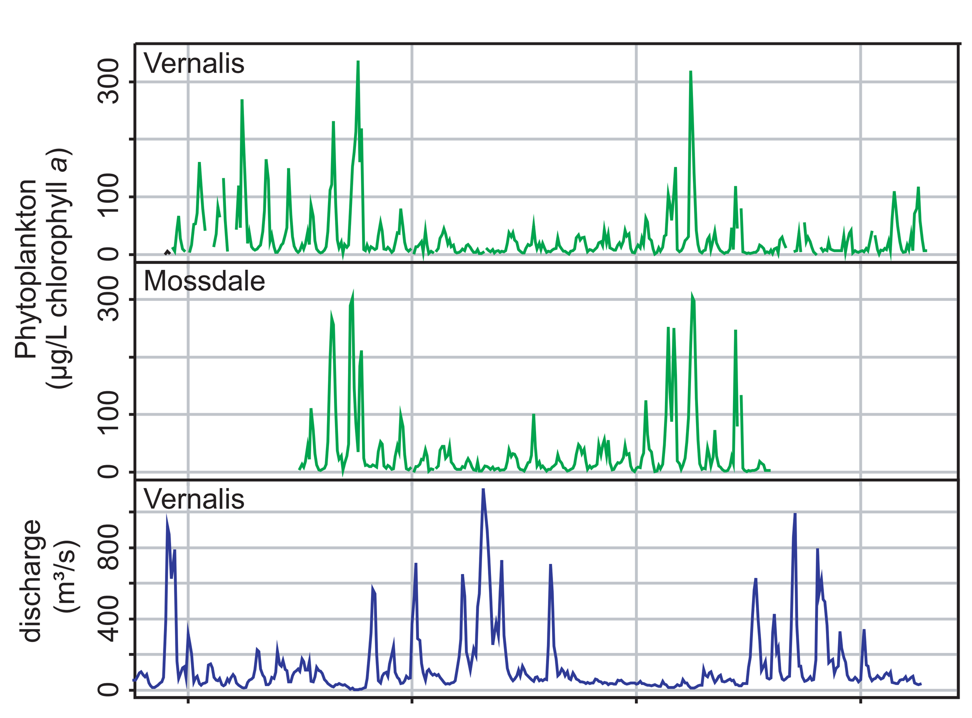

Figure 2. The size of the annual phytoplankton bloom upstream of the Ship Channel is highly variable. But note how the frequency of large blooms has decreased since the 1970s.

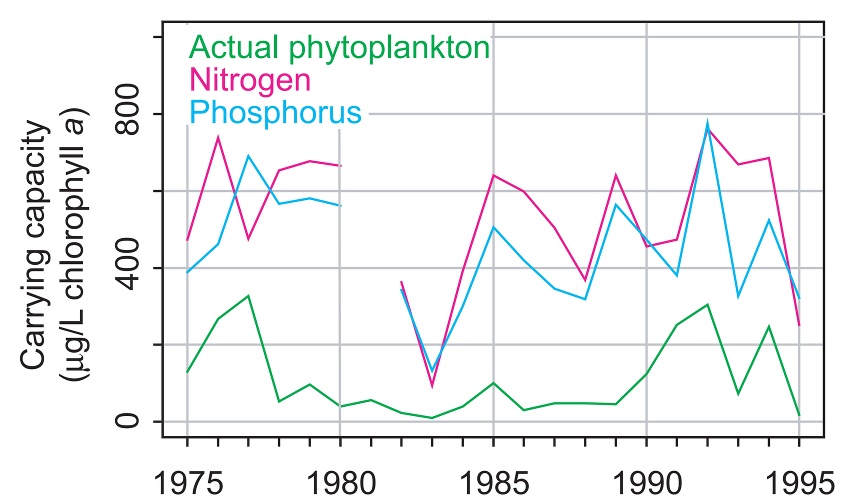

Figure 3. Nitrogen and phosphorus concentrations (as well as silicon) are sufficient to support much larger bloom sizes than actually observed at Vernalis. These carrying capacity estimates take into account the effect of water clarity, temperature, and nutrient concentrations on chlorophyll content.

The unexpectedly low levels did not occur because of nutrient limitation. Like many estuaries in agricultural watersheds, the tidal San Joaquin River has high nutrient concentrations originating in fertilizer and animal waste. At the peak of the annual bloom, most often in July, nutrients are usually sufficient to support a much higher population level at Vernalis (Figure 3). We found that phytoplankton biomass may become limited by nitrogen or phosphorus as cells continue to multiply on the way downstream toward the Ship Channel, but only in extremely dry years.

Transparency in the river is generally low, mainly because of a high concentration of mineral suspensoids; phytoplankton growth rate is probably light-limited. Phytoplankton concentration therefore depends primarily on river discharge, which determines the travel time and resulting cumulative light exposure in transit downstream. The flow rate around the time of the annual phytoplankton bloom in particular appears to control bloom size (Figure 4). Discharge below about 50 m³/s especially seems to promote large blooms. There is an additional effect not directly related to flow that resulted in larger blooms in earlier years; the cause is as yet unknown, but its impact is secondary.

Flow management. The long-term change in bloom size and its dependence on discharge leads to the question: Has early-summer discharge changed in some systematic way since the 1970s? Flow in the tidal San Joaquin River is highly managed, responding to storage-and-release patterns from upstream reservoirs on the mainstem and three tributaries: the Merced, Tuolumne, and Stanislaus rivers. Construction of Friant Dam on the mainstem was completed in 1942. The seasonal flow pattern at Vernalis has since changed markedly, typically with lower flows during March-July and higher during September-December (Figure 5, top panel). Combined with high agricultural nutrient sources, lower flow makes possible the large phytoplankton blooms observed by the monitoring program.

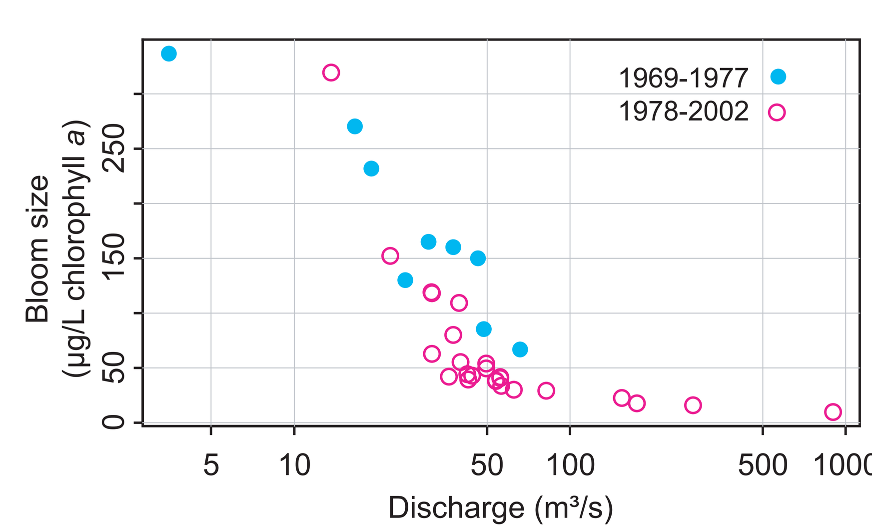

Figure 4. The peak of the annual phytoplankton bloom at Vernalis, usually in July, depends on concurrent river discharge. Bloom sizes earlier in the record tended to be higher, even when flow rates are taken into account. The reason is not yet known, although grazing changes are suspected.

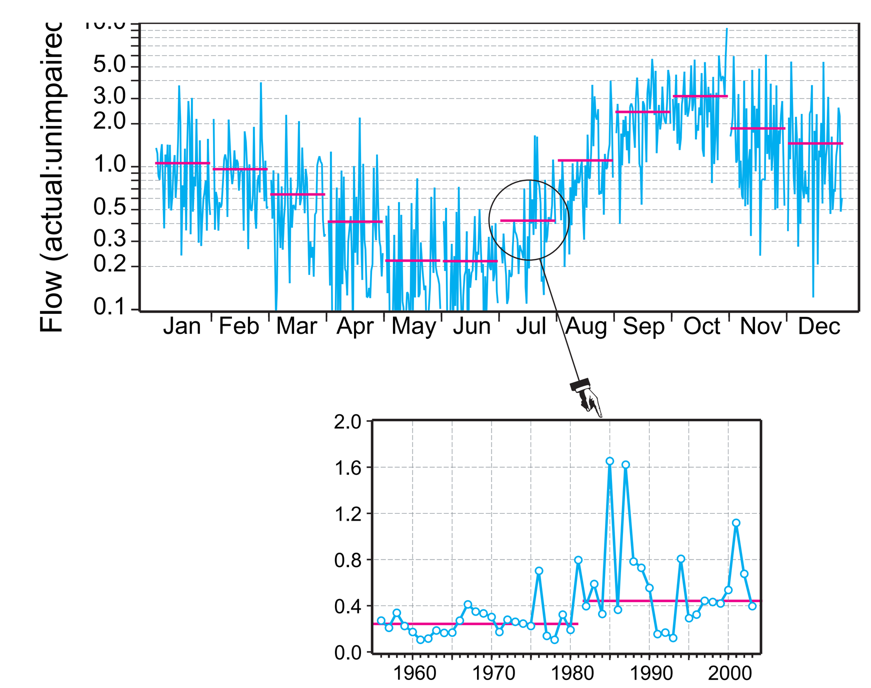

Figure 5. Median values of river discharge at Vernalis are typically much lower in July than they would have been under conditions of full natural flow (horizontal lines in top panel), although year-to-year changes for any given month are very large (time series underneath each median). A closer look at July shows that the median has almost doubled since 1982 (bottom panel).

The last of the large reservoirs, the New Melones on the Stanislaus, was constructed in 1979, and the reservoir filled in 1982 (Figure 6). One effect has been almost a doubling of median July flow, and in some years July flow has exceeded the unimpaired level (Figure 5, bottom panel). During 1982-2002, July flow exceeded the 50 m³/s threshold 11 times, whereas during the prior 21 years, it exceeded the threshold only 6 times (Figure 7). Even during dry and critically dry years, flow now approaches the threshold. This alone is sufficient to explain the long-term change in bloom magnitude.

Discharge downstream of Mossdale is further affected by the flow split at Old River, which in turn depends on water exports into federal and state water projects and on the presence/absence of a temporary rock barrier (Figure 1). We used a model for growth rate to estimate that residence time changes between Mossdale and the Ship Channel due to exports have resulted in more than a doubling of peak concentrations reaching the Channel in some years.

Conclusions. The observations and analyses in this study led to a specific conception of bloom control in this critical reach of the tidal San Joaquin River, summarized by the cause-and-effect diagram of Figure 8. Currently, the year-to-year variability in biomass is dominated by the path leading from climate and water management (reservoirs, exports) through early summer discharge to residence time. Other paths also represent opportunities for management, especially reduction of watershed inputs of macronutrients, which should be a long-term goal. The large difference between actual peak phytoplankton level and nutrient carrying capacities, however, indicates that only very large—and thereby difficult to implement in the short term—decreases in nonpoint nutrient sources could limit phytoplankton concentration reliably. A complication is added by the presence of light-limited growth rates, as a reduction in watershed inputs of mineral suspensoids without sufficient reduction in macronutrients could increase growth rate and ultimately biomass.

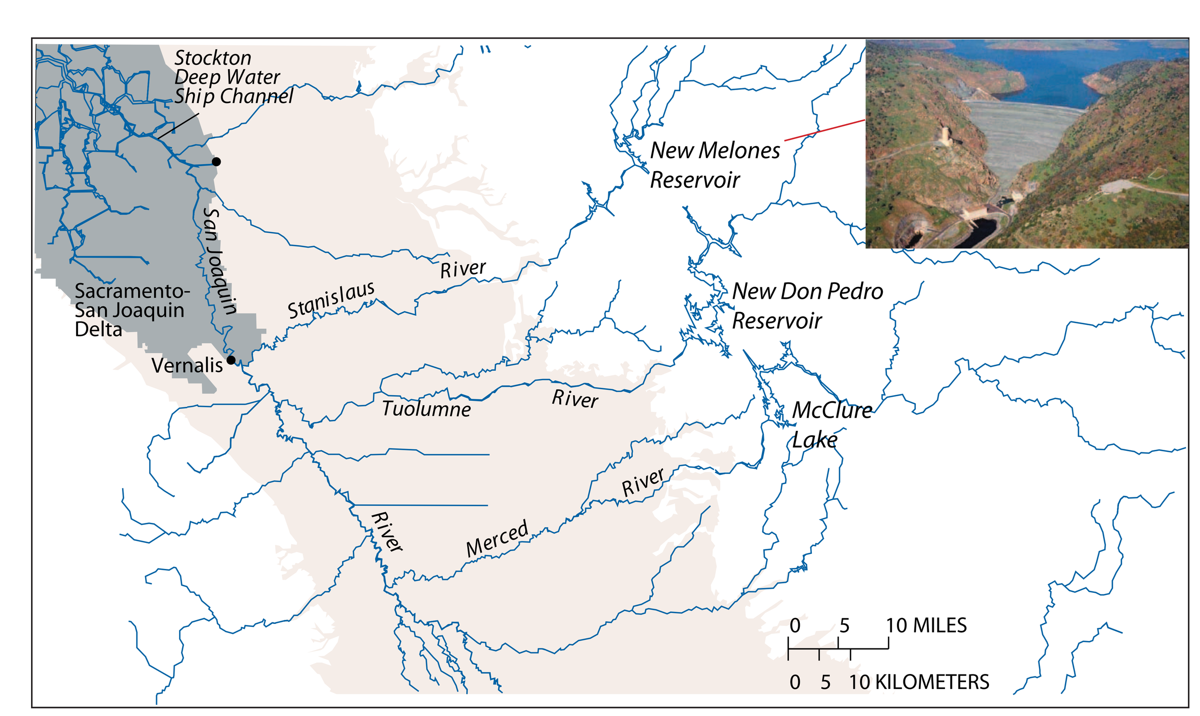

Figure 6. The major dams on the three main tributaries of the San Joaquin River were constructed in 1967 (Merced), 1971 (Tuolumne), and 1979 (Stanislaus). The Friant Dam is further south on the mainstem.

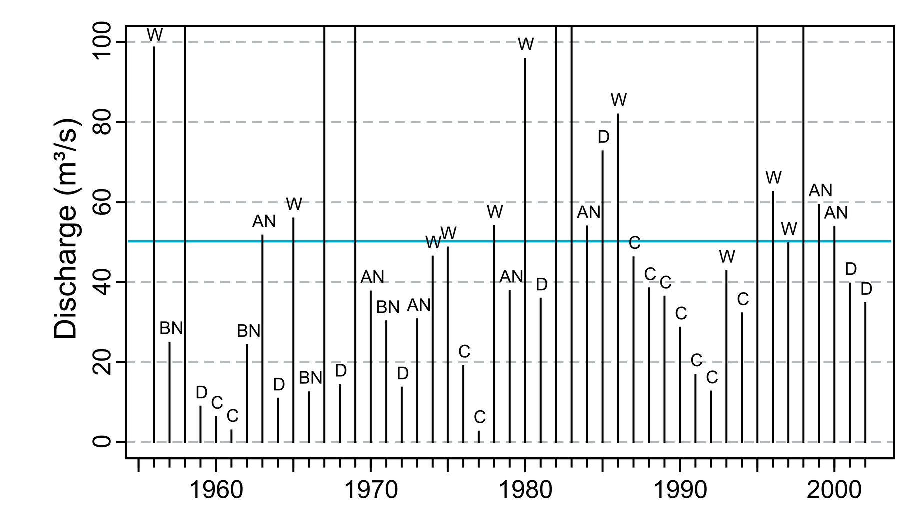

Figure 7. July river discharge at Vernalis in dry and critically dry years is generally higher since the New Melones Reservoir was filled in 1982; drought conditions no longer necessarily imply blooms > 200 µg/L chlorophyll a. Water year types: C, critically dry; D, dry; BN, below normal; AN, above normal; W, wet.

The remarkable sensitivity of peak phytoplankton biomass to early summer discharge is both a liability and an opportunity. Current managed levels of early summer discharge, in conjunction with high nonpoint nutrient supplies, have increased the frequency of blooms since pre-impoundment times. For the same reason, storage-and-release management offers a near-term approach for intentional management of blooms.

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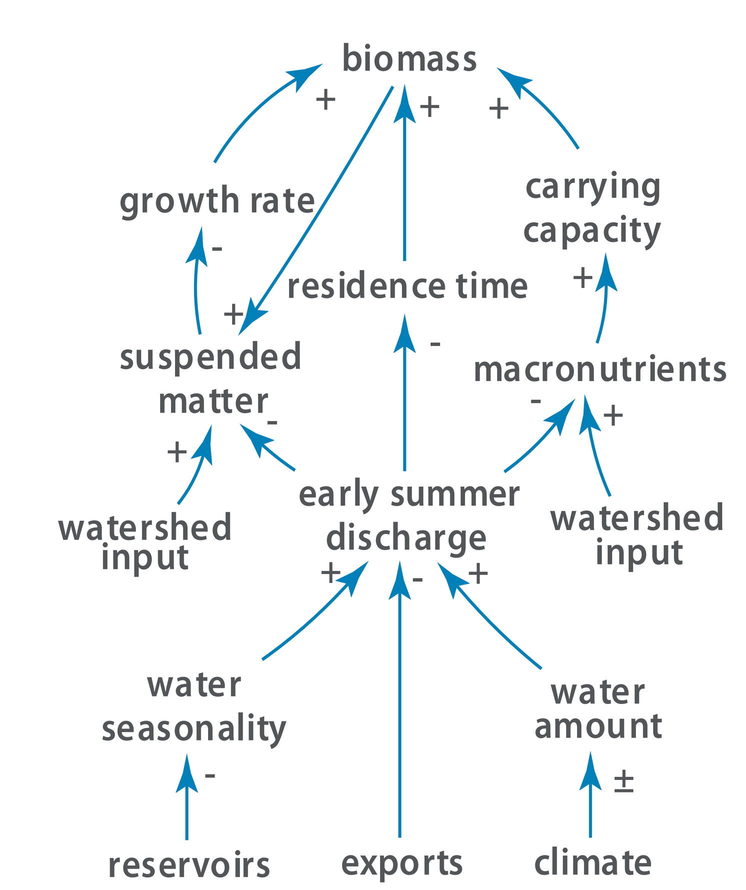

Figure 8. Phytoplankton biomass is the result of a complex interplay of mechanisms, but change in early summer river discharge acting through residence time has been the central reason behind historical variability at the annual scale.